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TECHNICAL REPORT 86-1

THE USE OF GRANULATED BLAST FURNACE SLAG IN CONCRETE

materials bureau technical services division

FEBRUARY, 1986

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February, 1986

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M.A.P. CODE 7.42-6-86-1

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ABSTRACT

A structural concrete project was selected by NYSDOT to evaluate the use of granulated blast furnace slag in concrete. The project was the construction of two new bridges over the Chenango River and Overflow Channel on County Road 32A in Chenango County, Contract D500186. A granulated slag known as NewCem was used. NewCem is a product of Blue Circle-Atlantic Cement Co. and was substituted for 50% by weight of the portland cement in all concrete items. The granulated blast furnace slag was required to meet ASTM 989, Grade 100. The NewCem was pre-tested and pre-accepted at Atlantic's facility in Ravena, New York. Results of the project indicate that the granulated blast furnace slag met all specification requirements and the properties of the concrete were at least equal to those of conventional portland cement concrete.

INTRODUCTION

In March of 1983, the New York State Department of Transportation (NYSDOT) began looking at granulated blast furnace slag (GBFS) as a partial replacement for portland cement. The material evaluated was a product of Blue Circle-Atlantic Cement Co. known as NewCem. The NYSDOT initiated a full laboratory testing program to determine the properties of concrete containing various amounts of GBFS as portland cement replacement.

In late 1984, with the lab evaluation complete, NYSDOT decided to do an experimental project requiring GBFS as a 50% replacement by weight for the portland cement.

OBJECTIVE

The NYSDOT initiated a structural concrete project in March, 1985 to evaluate whether a 50% by weight substitution of portland cement with GBFS would create any problems in constructing a new bridge structure.

PROJECT DESCRIPTION

The project selected to evaluate the use of GBFS concrete was the new construction of a bridge on Route 32A over the Chenango River in Norwich, New York, Chenango County. The bridge has two spans of 93.5 feet each.

GBFS was specified for all portland cement concrete items on the project.

The general contractor for the project was Economy Paving, Cortland, New York. Bid prices for the various items requiring GBFS concrete were as follows:

Item	Quantity	GBFS Concrete Project Bid Price	Conventional Concrete Average Bid Price
Concrete for Structures, Class A	55 c.y.	334.00	391.15
Concrete for Structures, Class B	183 c.y.	354.00	290.65
Concrete for Footings, Class B	107 c.y.	214.00	173.43
Structural Slab Concrete (Optional Forming System)	7,087 s.f.	15.50	14.93
Concrete for Structures, Class E (Structural Approach Slab with Integral Wearing Surface)	546 s.f.	7.65	6.95

NOTE: The contractor chose the specification option to substitute Class A for Class B and to substitute Class H for Class E in the structural deck slab.

The bid prices indicate that the cost of the GBFS concrete was slightly higher then conventional portland cement concrete. The average bid prices for conventional concrete are generally lower except for Class A concrete. The average bid prices are from the 1985 bid prices for all projects in the Binghamton area.

GRANULATED BLAST FURNACE SLAG

The NYSDOT developed a specification and quality assurance procedure specifically for this project with the intent of using the results to set standards for the future.

A. Specifications

The GBFS was required to meet the requirements for Ground Iron Blast - Furnace Slag Grade 100 listed in ASTM C989.

The detailed GBFS specification for the project is in Appendix A.

B. Quality Assurance

The GBFS was considered for acceptance in stock lot quantities at the supply location based on sampling and testing by the NYSDOT's Materials Bureau.

The main features of the quality assurance procedure are as follows:

1. The GBFS supplier can fill either a silo or a bulk container (transporter) and request approval of the material by NYSDOT.

2. The GBFS will be sampled by NYSDOT personnel and the inlet and discharge lines sealed following the sampling. The GBFS transporter must remain at the supply point.

3. The NYSDOT tests the GBFS.

4. Upon acceptance, the GBFS is transported to the project under seal control.

C. Source

The GBFS supplied by Blue Circle-Atlantic Cement Company of Ravena, New York, was processed at the Bethlehem Steel Corp. plant in Sparrows Point, Maryland. The blast furnace slag is transferred from the steel plant to Blue Circle-Atlantic's processing plant on site. There it is water-cooled and quick-quenched. The material is then dried and ground.

GRANULATED BLAST FURNACE SLAG CONCRETE

The GBFS was required in all standard classes of concrete. No modifications to the standard construction specifications were made except for the weighing sequence at the batch plant.

A. Batch Plant

The concrete was produced at B&B Builder's Supply, Norwich, New York. The standard batching procedures for conventional portland cement concrete were used except for the following:

1. The GBFS was stored in a separate silo.

2. Provisions were made to proportion the GBFS to an accuracy of ±1 scale graduation.

3. The GBFS was weighed cumulatively with the cement and the GBFS was last in the weighing sequence. The batching delivery tolerance for each material draw weight was based upon the total weight of cement plus GBFS.

B. Mix Design

NewCem was substituted for 50% of the cement (by weight). The necessary adjustment for volume was made by the NYSDOT. This adjustment compensated for the difference in the specific gravities of the cement and NewCem.

The contract requirements specified that the NYSDOT give the contractor the concrete mix design. The mix designs for this project were verified in the laboratory by the NYSDOT. The properties of the NewCem concrete determined in the laboratory are given in Table 1, NewCem Concrete Mix Designs. Also shown are graphs of the actual strength gains for those Designs (See Figures 1 and 2). Test results for the sample representing the NewCem are listed in Appendix B.

TABLE 1
NEWCEM CONCRETE MIX DESIGNS

	Batch Weights (PCY)	
Concrete Class	Class A	Class H
Cement (lbs.)	303	338
Water (lbs.)	279	297
Sand (SSD) (lbs.)	968	1036
#1 Stone (1/2"-1/4") (lbs.)	976	886
#2 Stone (1"-1/2") (lbs.)	976	886
NewCem (lbs.)	303	338
Air Entraining Agent	10 oz.	12 oz.
Retarder	-	20 oz.
	Plastic Properties	
Slump	5 3/4"	5 1/4"
Air Content	7.0%	7.1%
Wet Unit Weight (pcf)	142.99	142.39
	Compressive Strengths (PSI)	
7 Days	3355	4645
28 Days	4670	6735
90 Days	5315	7305

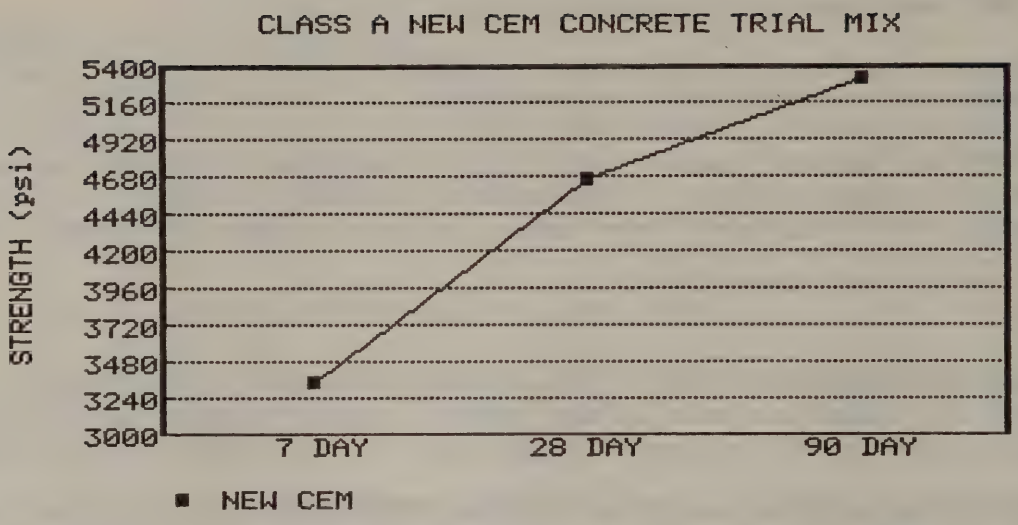

FIGURE 1

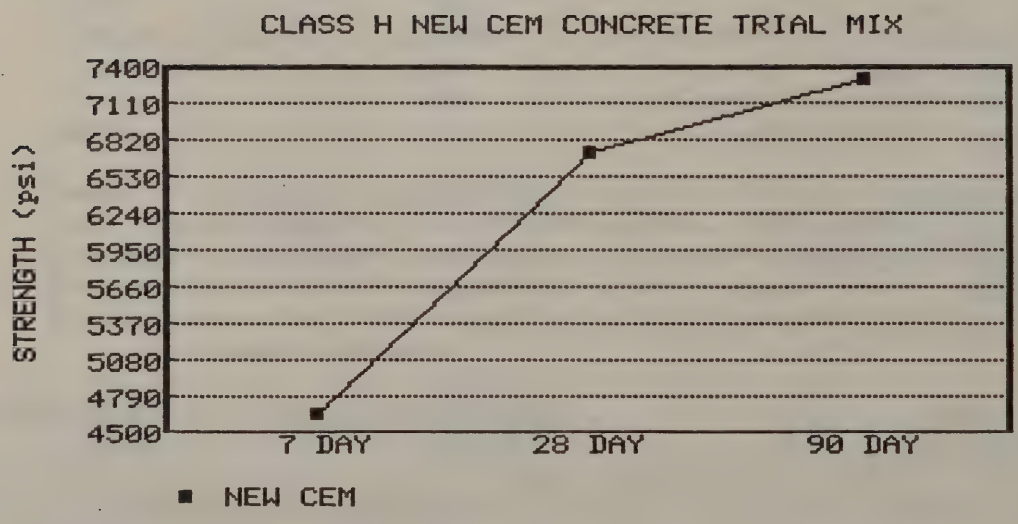

FIGURE 2

C. Field Placement

A total of 454 cubic yards of granulated slag/portland cement concrete were placed on this project.

The concrete was mixed in truck mixers using the transit mix method, and in place generally within one hour from the beginning of mixing. The NewCem concrete quality was accepted at the project site based on slump and plastic air content testing. Cylinders were made to monitor the potential compressive strength of the concrete.

The concrete was transferred from the truck mixer to the placement area by crane and bucket, or pump. The handling and placing characteristics of the mix were very similar to those of conventional concrete except that the flow properties of the mix appeared to be enhanced. The air entraining agent dosage had to be increased approximately 30-40% to obtain the desired air content.

D. Compressive Strength

The average compressive strengths of the Class A and Class H granulated slag/portland cement concrete at 28 days are 5576 and 6946 psi respectively. Figure 3 shows the actual strength gain for the Class H NewCem concrete (based on 6 X 12 cylinders). These results represent the actual average strength of the concrete in place. The coefficient of variation of Class A and H were 11 and 5% respectively. The strength gain appeared to be a little greater then that of conventional concrete. All data to date indicates that a high quality concrete was achieved.

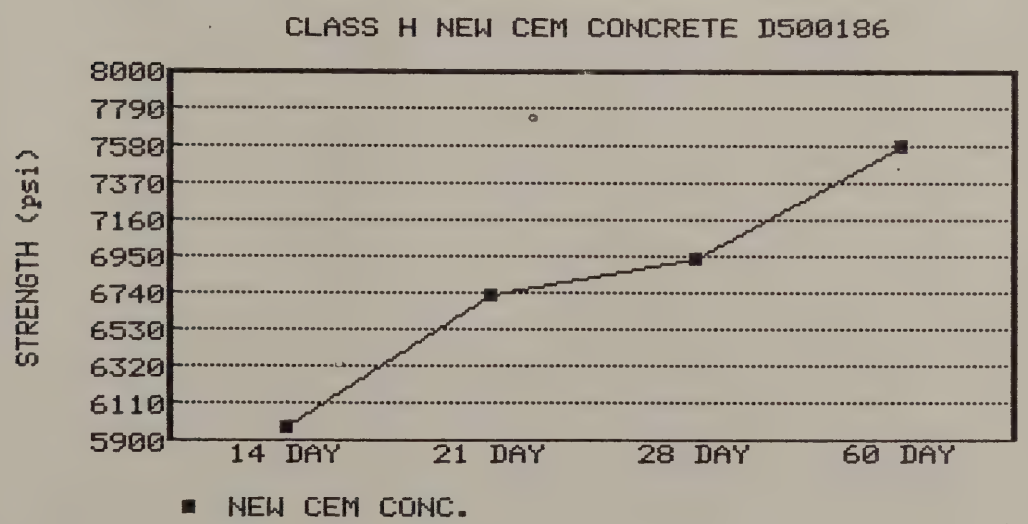

FIGURE 3

CONCLUSIONS

The project has been completed and the following conclusions can be drawn:

1. GBFS is available that meets specification limits. However, due to the present location of the processing facilies the use of GBFS may not be cost effective in New York.

2. The pre-test, pre-accept-at-the-source method of quality assurance for GBFS worked well for this project. This method, however, does tie up silos or transport tanks while testing and acceptance actions are being performed. A method of quality assurance based on the GBFS supplier's certification of test results and the NYSDOT monitor testing may be acceptable once a material history has been developed.

3. The air content is lower in the GBFS concrete as compared to conventional concrete at the same dosage rate. However, by increasing the dosage rate the desired air content is achieved.

4. Flowability and in turn workability of GBFS concrete is better than conventional concrete.

5. Strength gain of GBFS concrete is, on this project, better than conventional concrete.

The Department will continue to monitor this project. Items of interest will be the scaling properties due to deicing compounds and freeze thaw, the wearing characteristics as compared to conventional concrete, and the level of resistance to chloride permeability.

ACKNOWLEDGEMENTS

This study was performed under administrative supervision of James J. Murphy, Director, Materials Bureau. Others in the Materials Bureau who contributed significantly in the study were Paul E. Ducharme, John P. Ublacker and Eileen Gioia.

Considerable cooperation was provided by Blue Circle-Atlantic Cement Co., the Granulated Blast Furnace Slag supplier. Their cooperation is gratefully acknowledged.

APPENDICES

APPENDIX A

SPECIAL NOTE

PORTLAND CEMENT CONCRETE CONTAINING
GROUND GRANULATED BLAST FURNACE SLAG

All of the provisions of Section 501 shall apply unless otherwise modified by the terms of this note.

DESCRIPTION. All classes of concrete used on this project shall be manufactured with cementitious material composed of portland cement and ground granulated blast furnace slag. The actual percentage of ground granulated blast furnace slag allowed to be used is given in MATERIALS, Part 2, Composition of Mixtures.

The Contractor is specifically notified that concrete manufactured with ground granulated blast furnace slag as a constituent may have a reduced strength gain rate and/or an increased setting time, particularly in the lower range of the permissible temperature limits.

MATERIALS. The materials used for structural concrete shall comply with the material requirements of Section 501 - Portland Cement Concrete - General and the following:

1. General. Ground granulated blast furnace slag shall meet the requirements (including all chemical and physical properties) for Grade 100 listed in ASTM C 989.

   Storage. The ground granulated blast furnace slag shall be stored at its source of supply in approved weather-tight silos. Facilities shall be provided for maintaining such silos under Department seal control.

   All silos shall be completely empty and clean before ground granulated blast furnace slag is deposited therein unless the silo contains Department specification ground granulated blast furnace slag of the same type.

   Ground granulated blast furnace slag remaining in bulk storage at the source or distribution terminal for a period greater than one year after completion of tests shall be resampled and retested before shipment. However, ground granulated blast furnace slag which has been in bulk storage at sources or distribution terminals more than two years from the time of original manufacture shall not be used. No ground granulated blast furnace slag stored by the Contractor between the dates of November 1 and the following March 31 shall be used until retested and reapproved by the Materials Bureau.

   Shipment. All shipments of ground granulated blast furnace slag shall be made in accordance with procedural directives issued by the Materials Bureau. Conveyances for bulk ground granulated blast furnace slag shipment shall be of a type approved by the Department. The compartments of all such conveyances shall be completely empty and clean before any ground granulated blast furnace slag is loaded therein.

Inspection and Testing. All inspection and testing shall be in accordance with procedural directives issued by the Materials Bureau. When required by the Materials Bureau, ground granulated blast furnace slag shall be sampled by approved means to obtain continuous samples of ground granulated blast furnace slag and such samples shall be placed into a sealed container approved by the Materials Bureau. All samples shall be sent to the Materials Bureau. Tests for chemical and physical properties shall be in accordance with tests methods stipulated by ASTM C 989.

Basis of Acceptance. Ground granulated blast furnace slag will be considered for acceptance at the source or terminal locations in accordance with procedural directives issued by the Materials Bureau.

2. Composition of Mixtures. The class of portland cement concrete specified on the plans shall meet the requirements listed in Table 501-3, Concrete Mixtures except that ground granulated blast furnace slag shall be substituted for 50% of the cement (by weight) for all classes. Necessary adjustments will be made to the design mix proportions by the Department to compensate for the volume differential due to the ground granulated blast furnace slag substitution.

3. Proportioning. At least 60 calendar days prior to the start of the initial concrete placement, the Contractor shall furnish to the Department a sufficient amount of the job materials to produce 6 c.f. of each class of concrete so that the Materials Bureau can verify the proportions of the mixes to be incorporated into the work.

4. Ground granulated blast furnace slag shall be stored at the batch plant in a separate storage or holding bin and shall be protected from rain and moisture.

5. When ground granulated blast furnace slag is weighed cumulatively with the cement, ground granulated blast furnace slag shall be last in the weighing sequence and the batching delivery tolerance for each material draw weight shall be based upon the total weight of cement plus ground granulated blast furnace slag.

6. Both cement and ground granulated blast furnace slag weights shall be recorded as indicated on the batching scale within an accuracy of ±1 scale graduation.

APPENDIX B

NEW CEM TEST RESULTS

(NEW CEM USED IN LABORATORY VERIFICATION OF
NEW CEM CONCRETE MIX DESIGNS - D500186)

	Test Results	ASTM
Fineness (% Retained on No. 324 Sieve)	1.0	20 (max.)
Sulfide Sulfur (S), %	0.88	2.5 (max.)
Sulfate ion as SO_3, %	0.07	4.0 (max.)
Specific Gravity	2.93	-
Air Content of Slag Mortar, %	9	12 (max.)

Slag Activity Index, %:

7 Day Test Results	ASTM Grade 100	28 Day Test Results	ASTM Grade 100
94	75 (Min.)	117	95 (Min.)